Quantitative Assessment of Inhalation Exposures Generated from Floor Mopping Practices using Full-scale Chamber – A Pilot Study

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SUMMARY
In California, the rate of work-related asthma among cleaning workers is nearly triple the rate reported for all occupations combined. To reduce exposures associated with cleaning, it is important to develop science-based best cleaning practice guidelines. It encompasses a much broader set of practices than simply switching to less toxic cleaning products. This paper reports the first step of our current study aiming at recommending best floor mopping practices based on quantitative airborne exposure assessment. Five repeated controlled simulated-use experiments on bucket and cotton string mops were conducted in a 29.2m^3 environmental chamber. The diluted solution of an all-purpose cleaner with 2-butoxyethanol as the major ingredient was used. Quantitative exposure assessments were made for both TVOC using real-time monitors and for individual VOCs using integrated sorbent tube samples. Results show good measurement repeatability and suggest the proposed research method works. Study will continue as designed for other floor mopping procedures and to finally make best floor mopping practice recommendations.

IMPLICATIONS
This study demonstrates the validity of proposed measurement methods and the repeatability of simulated-use chamber test method for quantitatively evaluating airborne exposures associated with cleaning tasks. It also shows that exposures can be significant for both cleaning workers and bystanders present in the room after cleaning.

KEYWORDS

floor mopping, cleaning products, airborne exposures, chamber test, repeatability

INTRODUCTION
Janitorial cleaning activities are integral to on-going building maintenance and operation. There is increasing evidence that cleaning product use is associated with asthma and other respiratory illnesses among those who perform cleaning tasks or spend time in recently cleaned indoor environments (Zock et al. 2001; Rosenman et al. 2003; Bernstein et al. 2009; Pechter et al. 2005). Therefore, it is important to develop science-based best cleaning practice guidelines which often need quantitative assessment of exposures. A few previous studies have used simulated-use chamber experiments for such quantitative assessments (Singer et al, 2006, EWG report, 2009). In our study, we used a similar approach and focused on exposure differences caused by different cleaning methods, specifically, common floor mopping

procedures (e.g., bucket and microfiber string mops, bucket and cotton string mops, flat microfiber mopheads in buckets, and mop handle with reservoirs). The purpose of our study is to identify mopping practice procedures that can minimize inhalation exposures to chemicals emitted from cleaning products. As its first step, this paper describes the test method, repeatability and uncertainty.

METHODS

All the tests were conducted in a $29.2 m^3$ stainless steel lined chamber. The chamber floor was first covered by a plastic sheet. A vinyl flooring sheet of $5.87 m^2$ (corresponding to a loading factor of $0.2 m^2/m^3$) was then placed on top. A general purpose cleaner was used; the brand is one widely available in retail stores. Its Material Safety Data Sheet indicates that it contains only one ingredient with established exposure limit: 2-butoxyethanol (2-BE, <4%). The reported volatile organic compound (VOC) content is 3.8% by CARB Method 310 and 2.8% by SCAQMD Method 313.

Tests on bucket and cotton string mops were repeated 5 times (four tests by one test performer and the fifth test by a different performer). The tests followed a pre-defined protocol to investigate test repeatability and experimental uncertainty. The cleaning solution was prepared outside the chamber immediately before the test by dispensing 450 mL of full-strength cleaner into ~ 4.5 L of water (a dilution ratio of 1:10 suggested by the manufacturer for heavy-duty application) in a 20 L bucket. The test performer then entered the chamber with all the supplies to perform floor mopping. The $5.87 m^2$ of vinyl flooring was divided into two halves. The cotton string mop was submerged into the dilute cleaning solution, tilted to drain off the excess solution (without wrung), and then applied over half of the vinyl floor using 10 mop strokes (back and forth). The above wet mopping procedures were done twice for each half floor. Finally, for each half floor, the mop was submerged into the cleaning solution, fully wrung, and applied to the floor to complete the final mopping phase. The test performer then exited the chamber, removing all supplies. The whole procedure lasted about 8 minutes. Fig. 1 shows the bucket position and floor mopping routes taken for the tests. Figs. 2(a) and (b) illustrate how tests were conducted in chamber.

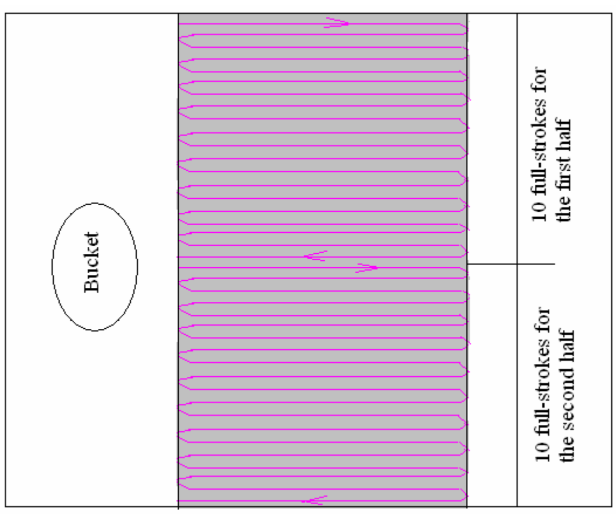
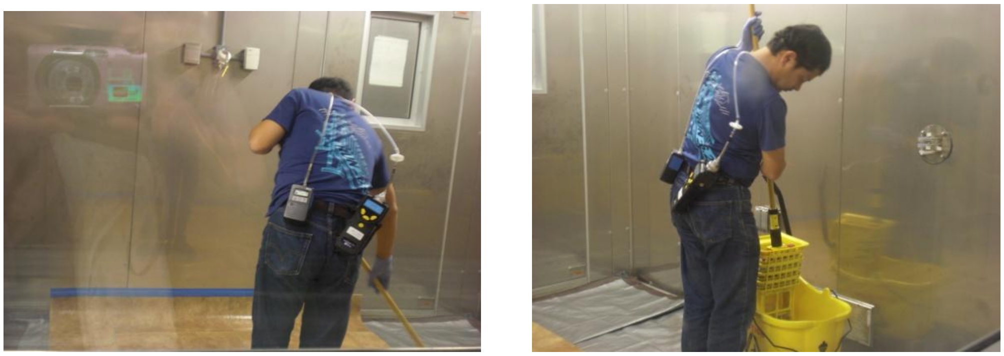


Figure 1 Detailed floor mopping routes and bucket position



(a) Floor mopping (b) Tilting mop

Figure 2 Test chamber and test set-up

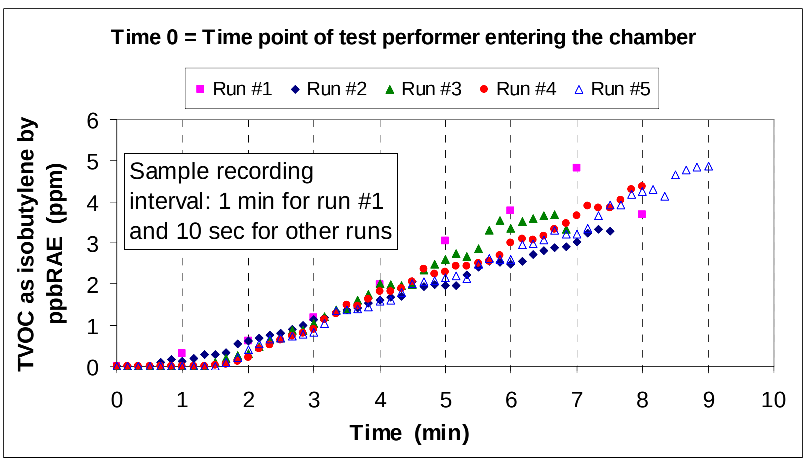
Clean ventilation air was mechanically provided. The air-exchange rate was checked before each test by measuring the concentration decay of injected CO_2. It was within 1.0±0.2ACH for all the tests. A mixing fan inside the chamber operated continuously to ensure good mixing. All the tests were conducted at room temperature (22±2^oC). Relative humidity (RH) was controlled at 50±5% for all the tests at the start.

Two real-time monitors were used to track the dynamic change of total airborne volatile organic compounds (TVOCs). One was photo ionization detector (ppbRAE3000, RAE Systems Inc., USA, Resolution: 1ppb for 0 to 9999 ppb range and 0.01 ppm for 10 to 99 ppm range, Calibration: Readings are 0ppb and 10ppm when calibrated by isobutylene using two-point calibration for zero and 10ppm). It was attached to the test performer's personal exposure as shown in Fig. 2. The other was photoacoustic spectroscopy (PAS) gas monitor (1412, INNOVA, Denmark, Resolution: 1ppb for the measurement range, Repeatability: 1% of measured value, Calibration: Readings are 51.6, 25.7 and 5.29ppm when calibrated using toluene at 51.5, 25.75 and 5.15ppm, respectively). The PAS monitored the TVOC concentration in chamber continuously during the floor mopping and ~12 hrs after the test performer exited the chamber. To quantify individual VOCs, a personal sampler was attached to the test performer's breathing zone for all the tests, and integrated samples were collected using Tenax TA sorbent tubes during the ~8 minutes of floor mopping. For test #2 and #3, integrated sorbent tube samples were also taken at a fix position inside the chamber (0.5m away from side wall at 1.6m height) during floor mopping. The tubes were then analyzed by ATD-GC/MS (Automated Thermal Desorber - Gas Chromatograph/Mass Spectrometer).

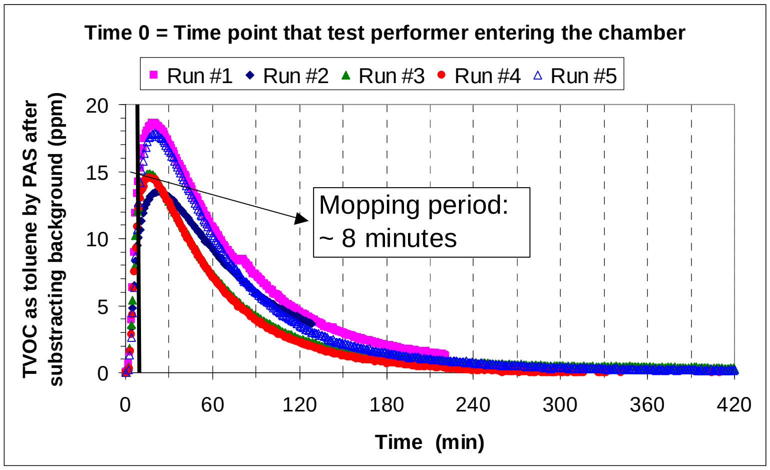
RESULTS AND DISCUSSIONS

Fig. 3(a) shows the TVOC concentrations measured by ppbRAE3000 for the test performer's personal exposure. The measured average concentration over test period for each test fell within the range of 1.5 to 2.0 ppm (average 1.7 ppm for the five tests). Fig. 3(b) shows the TVOC concentration measured by PAS gas monitor in the chamber during the tests and the flushing periods after. The peak TVOC observed for each experiment again fell within the range of 13.6 to 18.6 ppm (average15.9 ppm for the five tests), suggesting reasonably good test repeatability. In addition, we noted that peak concentrations were delayed until about 6 – 10 minutes after the test performer exited the chamber. This suggests that people occupying the room immediately after cleaning can experience even higher exposures than the person involved with cleaning. Singer et al. (2006) reported similar phenomena (delay of peak concentrations for chemicals such as 2-BE and persistence of elevated chemical concentrations after cleaning) from their study. Although real-time monitors are very useful tools for tracking the dynamic concentration change, it should be noted that it is generally not appropriate to directly compare the TVOC concentration values obtained from different types of monitors (PID, PAS, etc.) for a complex VOC mixture since they each have a different response ratio to each individual VOC constituent.

As for the integrated individual measurements for the floor-mopping period, 2-BE and d-limonene were the two major VOCs detected. Fig. 4 shows their concentrations (based on individual compound calibrations) for samples taken at test performer's breathing zone (for test #1 to #4 due to the lost of sample from test #5 during GC/MS analysis) and at the fixed position inside the chamber (for test #2 and #3 only). Result variations were larger than expected. The real-time TVOC monitors suggested the highest TVOC concentration in run #1, but this was not reflected in sorbent tube analysis. The most possible reason was that we used a larger sampling flow rate (160 ml/min) and therefore sampling volume (~ 1.3 Liter) in test #1. The amount of VOCs detected reached above the upper limit of calibration curve, resulting in an underestimate of real concentrations. The sampling flow rate (therefore sampling volume) used in test #2 to #5 was then reduced to 65 ml/min (about 40% of that used in test #1), and the correspondence between TVOC measured by real-time monitors and that measured by sorbent tube GC/MS analysis seemed improved significantly. The general trends of lowest TVOC concentration in test #2 and similar TVOC concentration levels in test #3 and #4 were consistently observed for PID, PAS as well as GC/MS measurements. The sum of 2-BE and d-limonene concentration measured at test performer's breathing zone ranged from 3229μg/m^3 to 4331μg/m^3. The variation was still significant but not totally unacceptable, considering the difficulty to control exact time and the amount of cleaning solution applied for each step in such floor-mopping test. As for the samples taken at the test performer's breathing zone and at the fixed position inside the chamber, the measured concentrations were reasonably close suggesting the good mixing condition in chamber. Fig. 5 shows an example gas chromatograph from GC/MS analysis of tube samples. As show in Figure 5, several other VOCs such as α-pinene and g-terpinene were also detected, but they were at much lower concentrations (some close to detection limits) so that their concentrations were not reported in this paper.



(a) TVOC personal exposure by PID



(b) TVOC chamber concentration by PAS
Figure 3 Results from real-time monitors

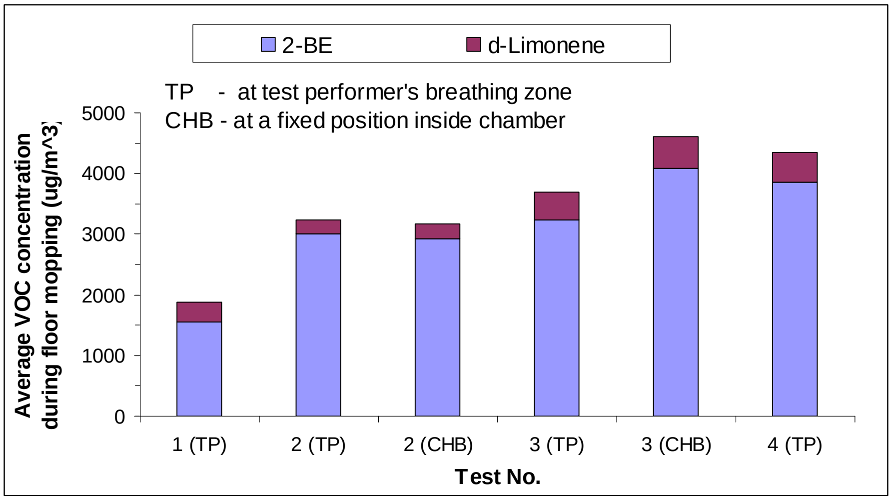


Figure 4 Individual VOC measurement results from GC/MS analysis

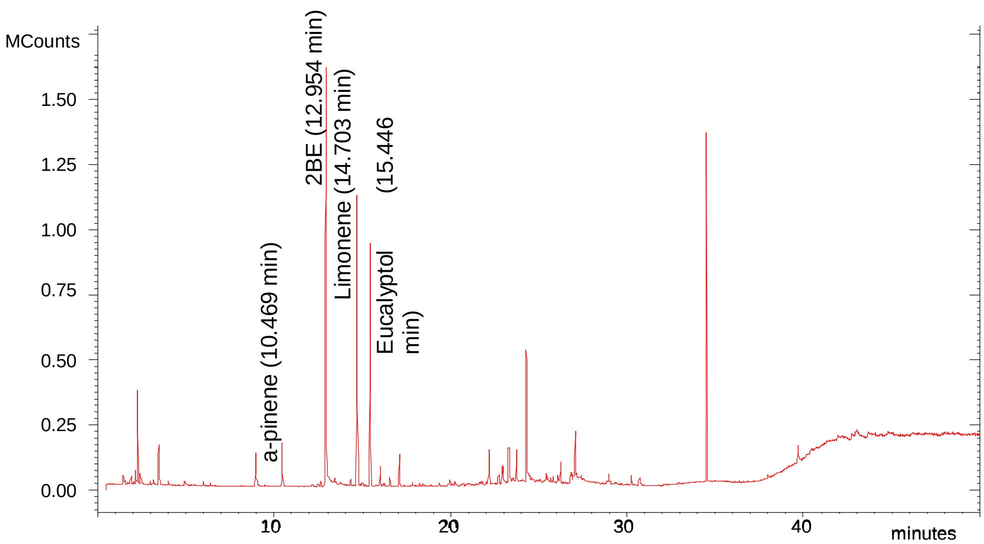


Figure 5 Example gas chromatograph from sorbent tube analysis

CONCLUSIONS

This paper focused on investigating the test repeatability and uncertainty for using simulated-chamber experiments to quantify and compare the airborne exposure differences caused by different cleaning methods. It represented the first step of our current study aiming at recommending best floor mopping practices based on quantitative airborne exposure assessment. Results of our preliminary experiments demonstrated that:

(1) Measurement repeatability can be regarded as reasonably good for both real-time TVOC monitoring and integrated samples for individual VOCs for testing cleaning methods by simulated-use chamber experiment, considering the various uncertainties involved in such floor mopping tests.
(2) Real-time TVOC monitors can be useful tools for comparing exposure dynamics and evaluating various cleaning procedures.
(3) Exposures of bystanders present in the room immediately after floor mopping can be as significant as those of the cleaning workers.

Study will continue as designed for other floor mopping procedures and to finally make best floor mopping practice recommendations.

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